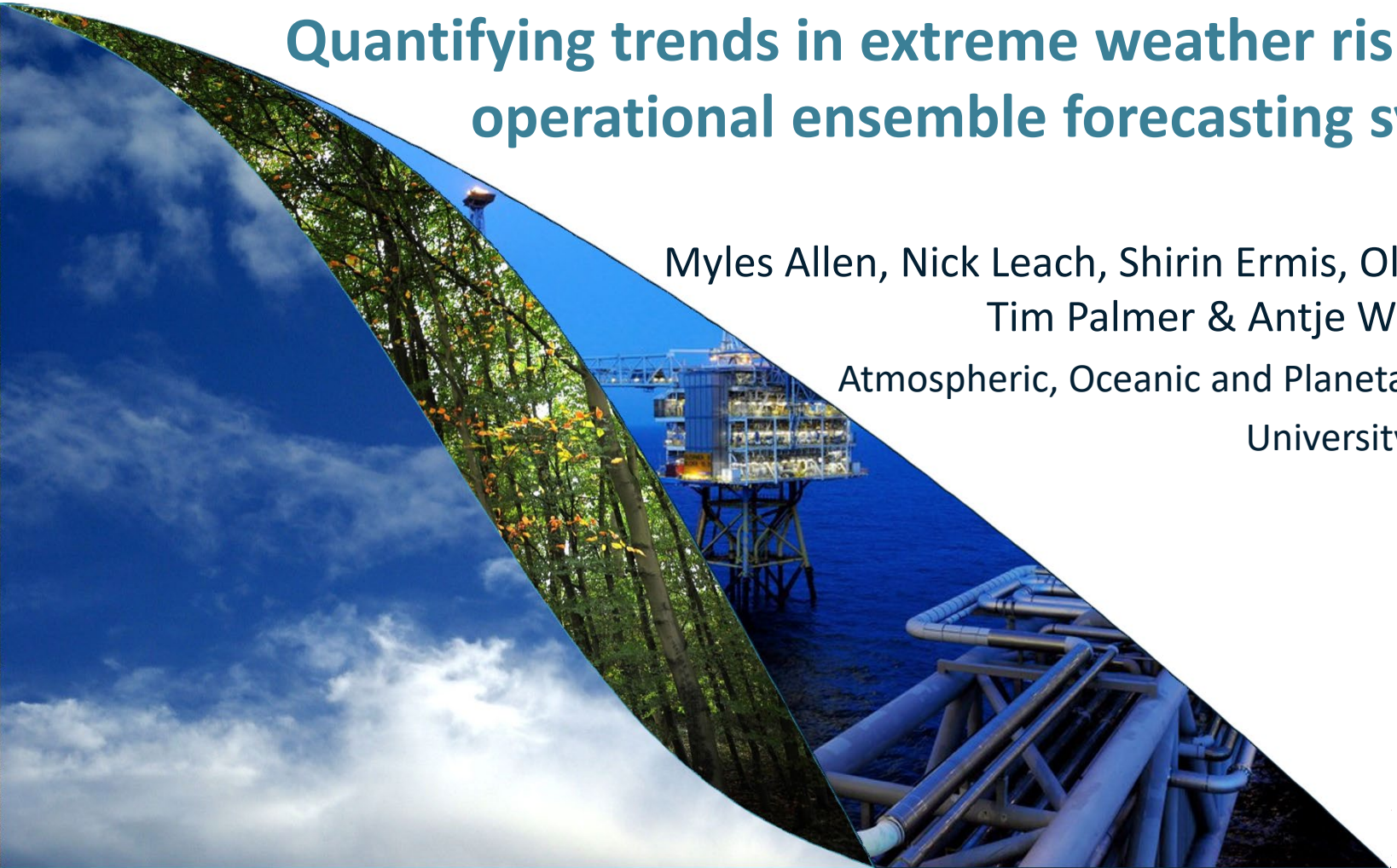
Quantifying trends in extreme weather risk using operational ensemble forecasting systems



Myles Allen, Nick Leach, Shirin Ermis, Olivia Ayim, Tim Palmer & Antje Weisheimer

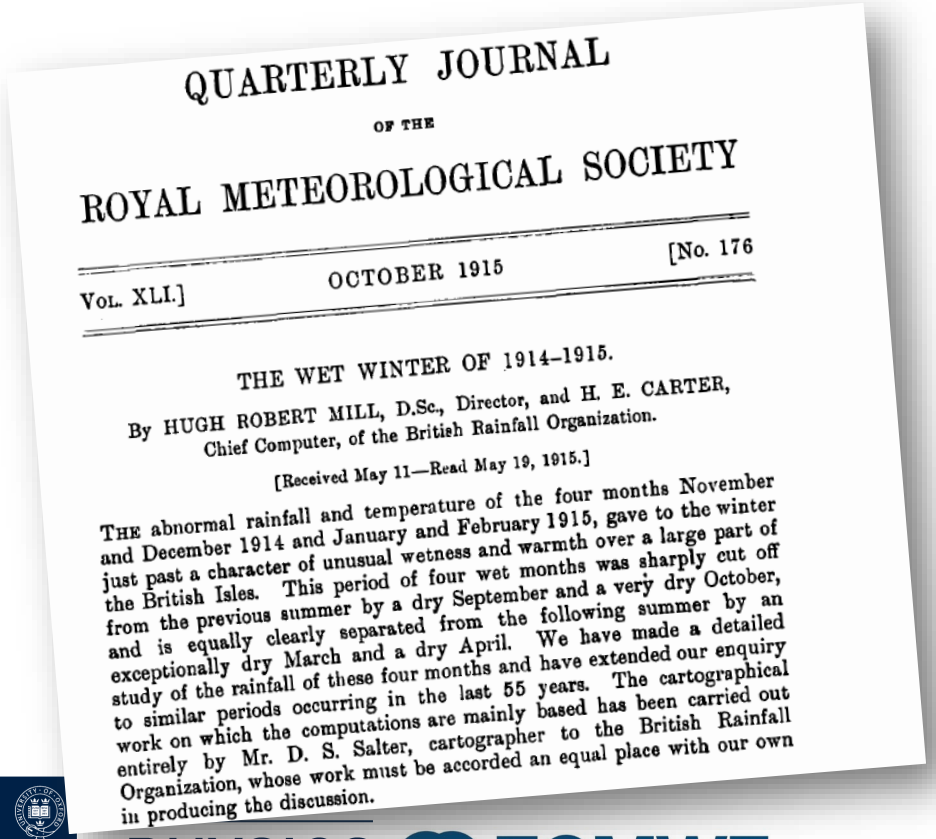
Atmospheric, Oceanic and Planetary Physics

University of Oxford

NET ZERO

UNIVERSITY OF OXFORD

People have always been interested in attribution



QUARTERLY JOURNAL

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VOL. XLI.] OCTOBER 1915 [No. 176

THE WET WINTER OF 1914–1915.

By HUGH ROBERT MILL, D.Sc., Director, and H. E. CARTER, Chief Computer, of the British Rainfall Organization.

[Received May 11—Read May 19, 1915.]

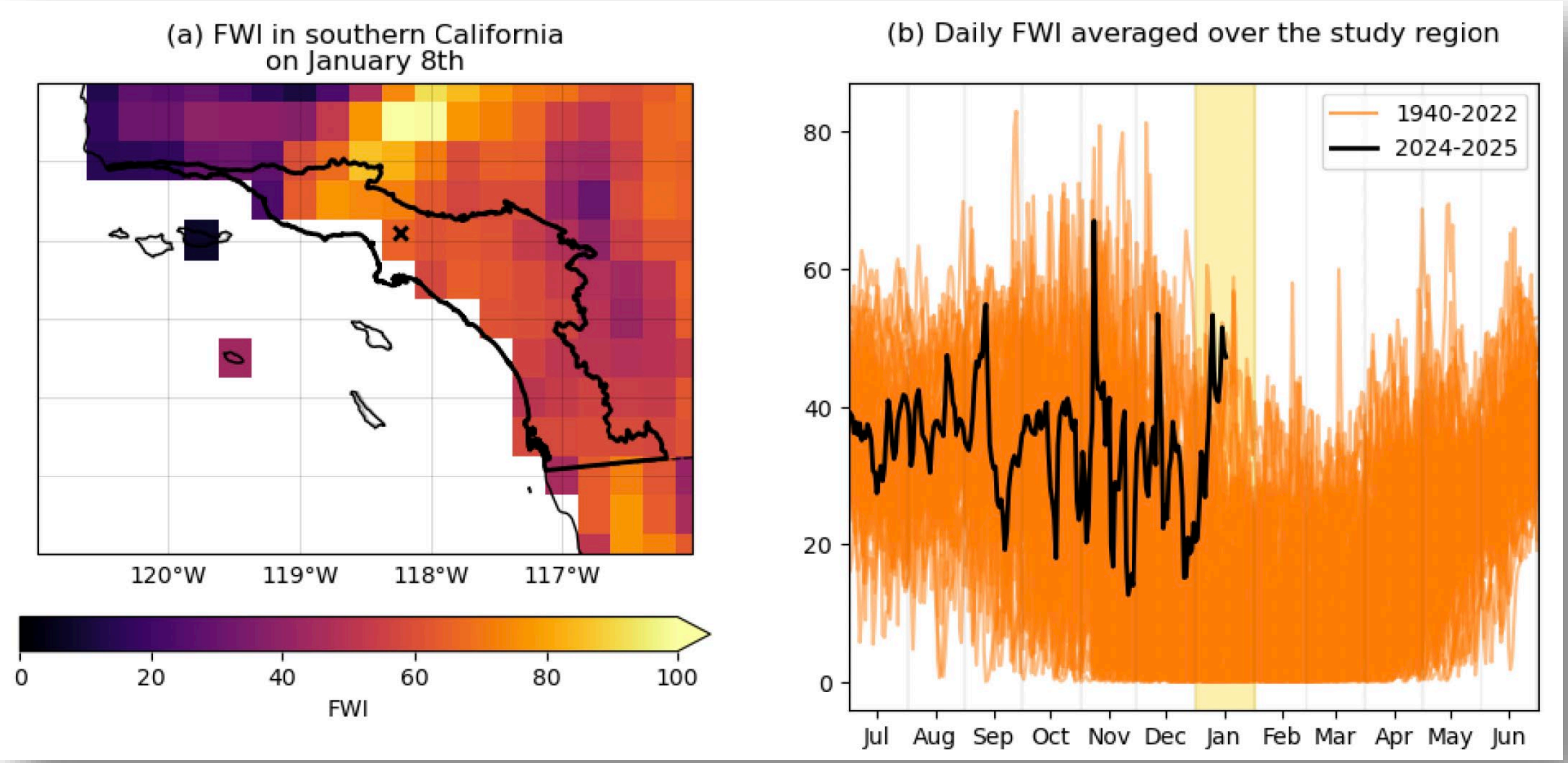
THE abnormal rainfall and temperature of the four months November and December 1914 and January and February 1915, gave to the winter just past a character of unusual wetness and warmth over a large part of the British Isles. This period of four wet months was sharply cut off from the previous summer by a dry September and a very dry October, and is equally clearly separated from the following summer by an exceptionally dry March and a dry April. We have made a detailed study of the rainfall of these four months and have extended our enquiry to similar periods occurring in the last 55 years. The cartographical work on which the computations are mainly based has been carried out entirely by Mr. D. S. Salter, cartographer to the British Rainfall Organization, whose work must be accorded an equal place with our own in producing the discussion.

"An explanation which has been most readily accepted by the general public, and has even found favour among a few meteorologists, is that the heavy artillery firing in France and in Flanders is the primary cause of the unusual wetness of the past winter."

But attribution of trends is actionable

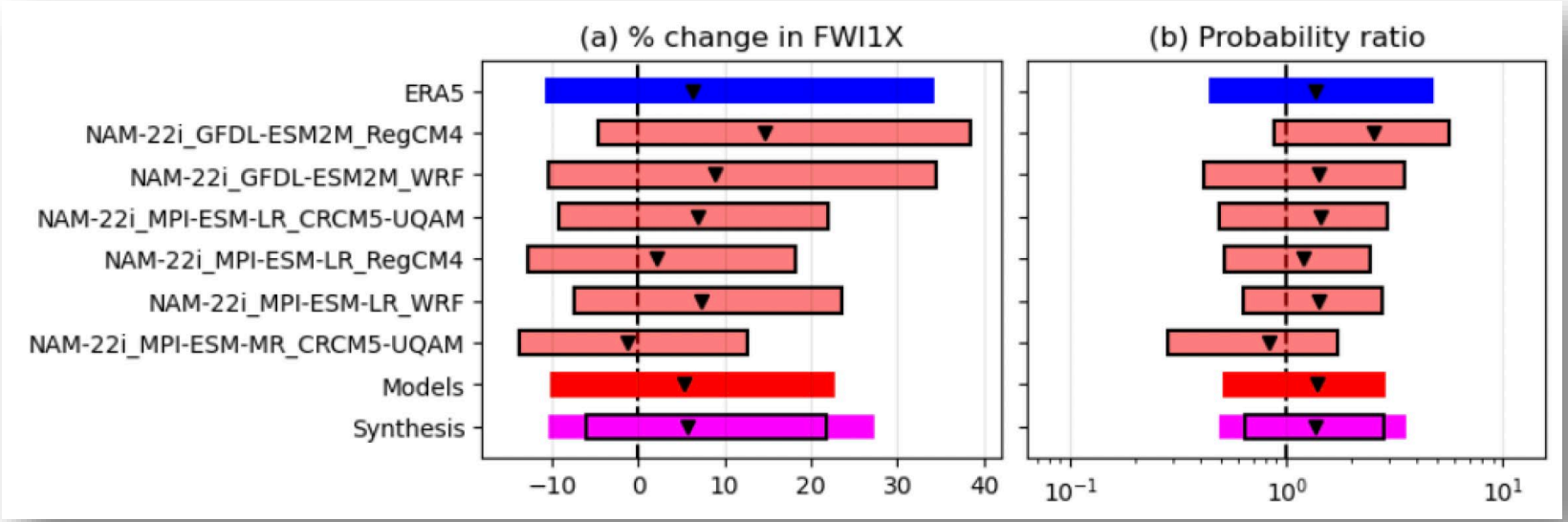
Lytton, British Columbia, 2021

A more recent example



Barnes et al, World Weather Attribution, 2025

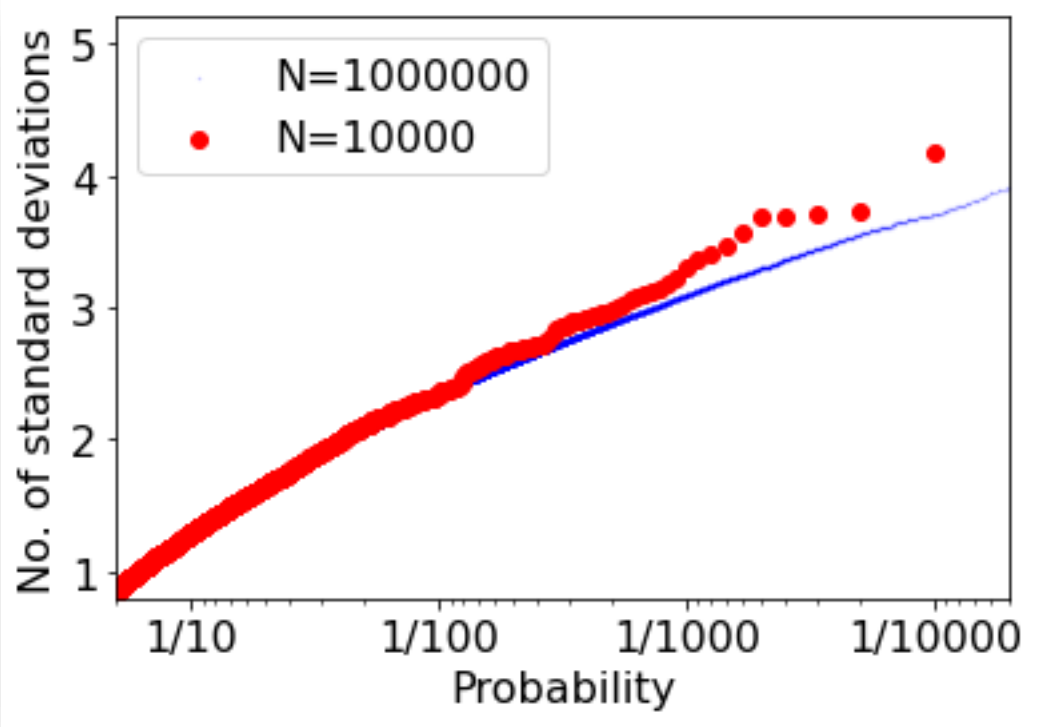
A more recent example



Modest best-estimate increase in maximum 1-day Fire Weather Index with broad range of uncertainty

Barnes et al, World Weather Attribution, 2025

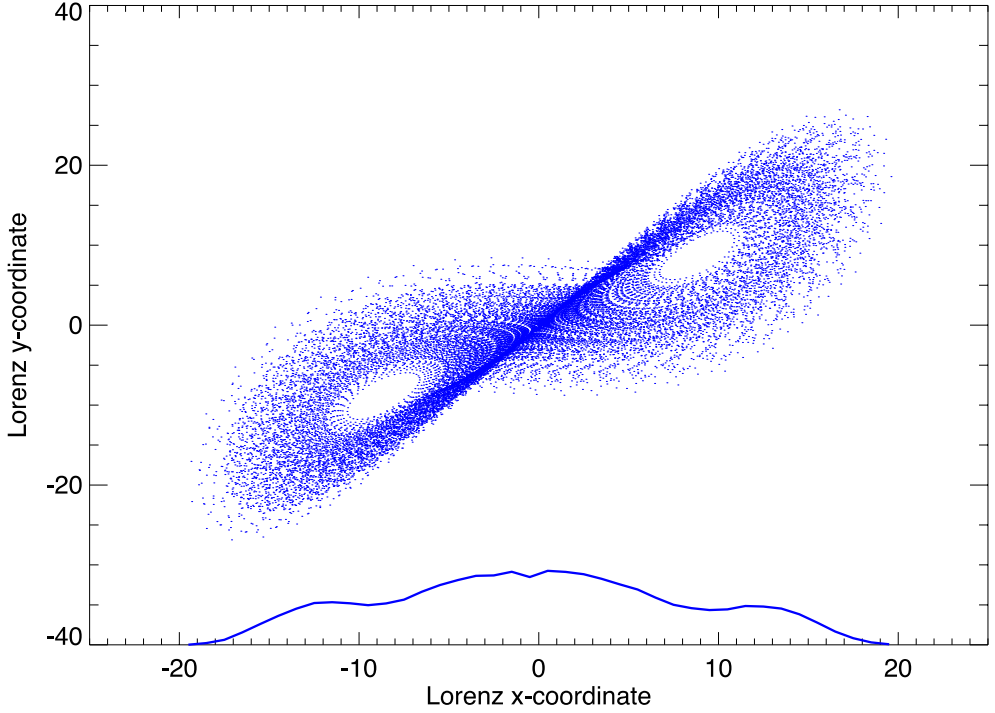
Uncertainties in return times for even the simplest random process



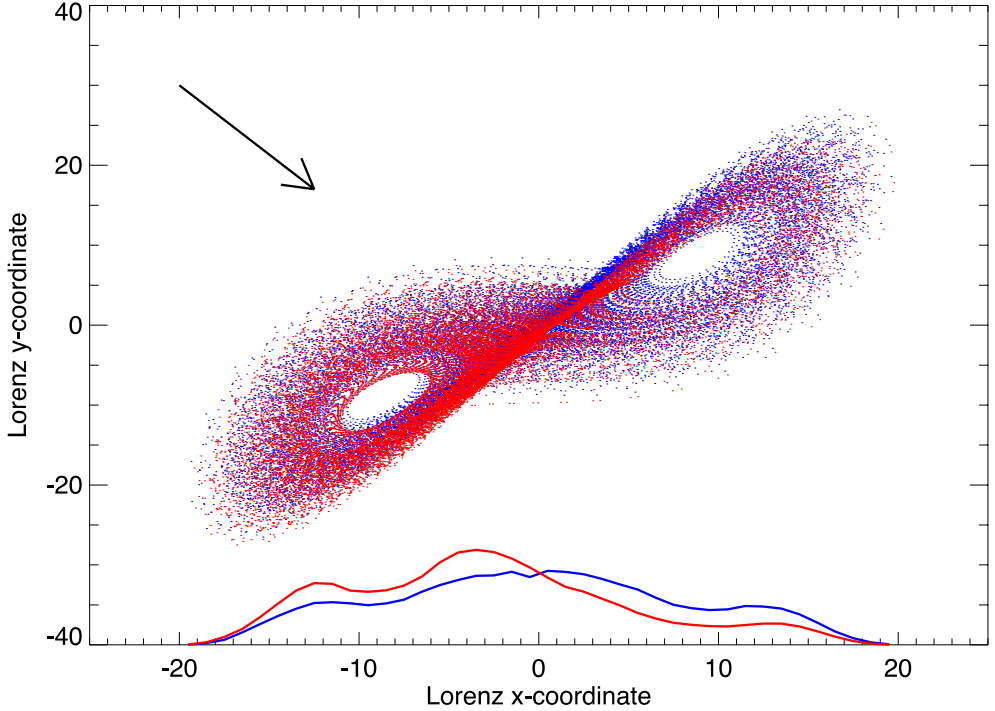
Return times for a more interesting process

Sergei Klishin

Explaining how climate change affects weather in a simple dynamical system



Explaining how climate change affects weather in a simple dynamical system



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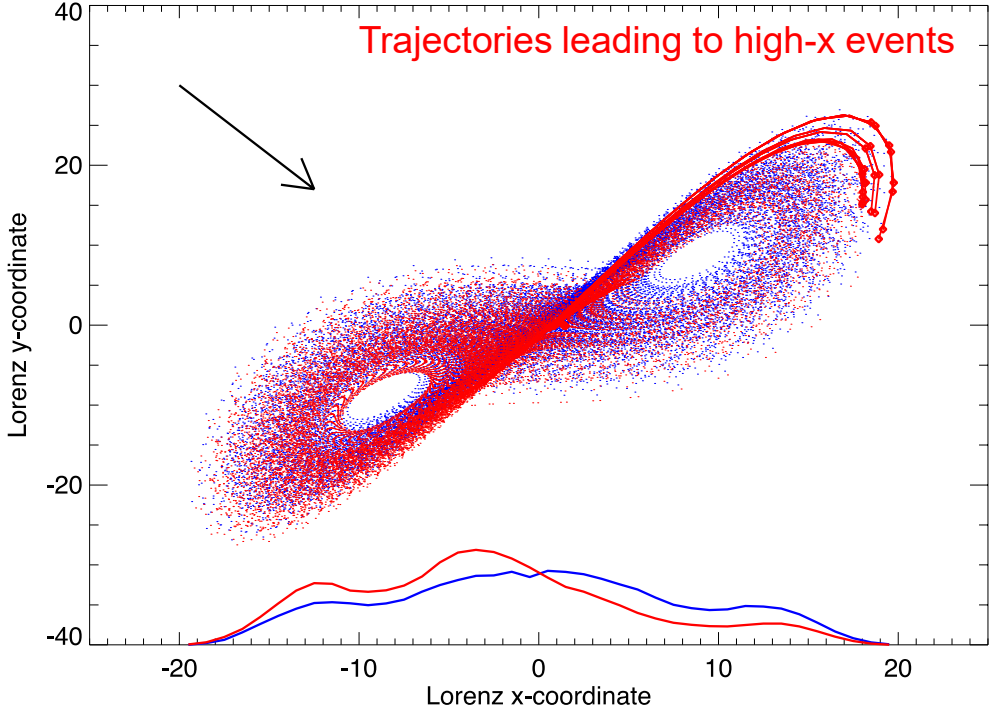

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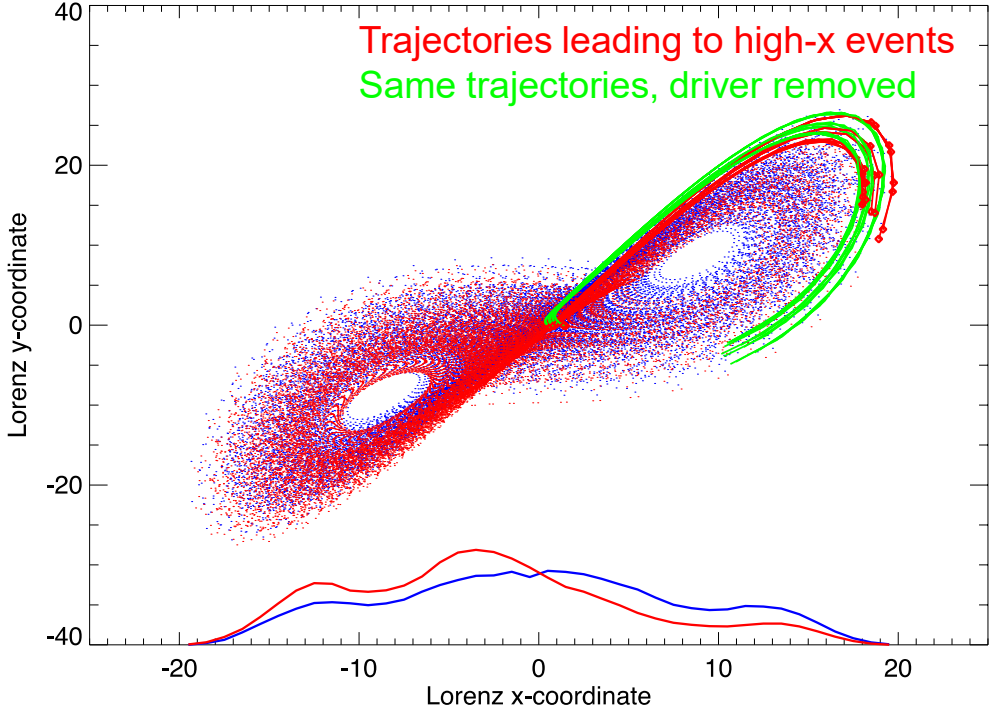
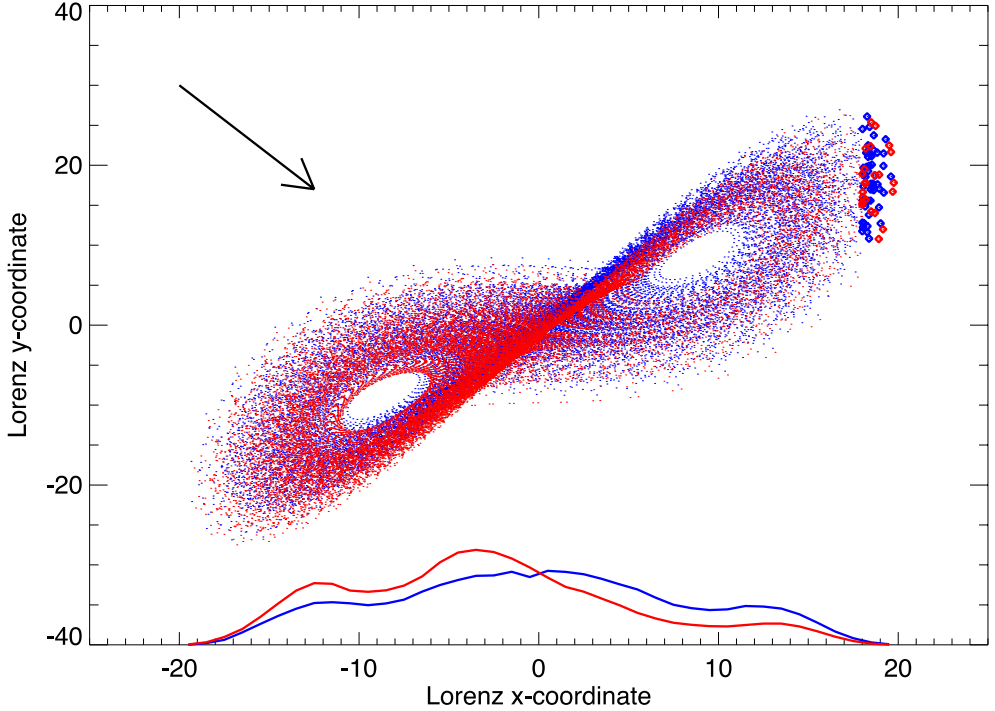


External driver **increases the magnitude** of "high-x" events

Explaining how climate change affects weather in a simple dynamical system



External driver **reduces the frequency** of "high-x" events

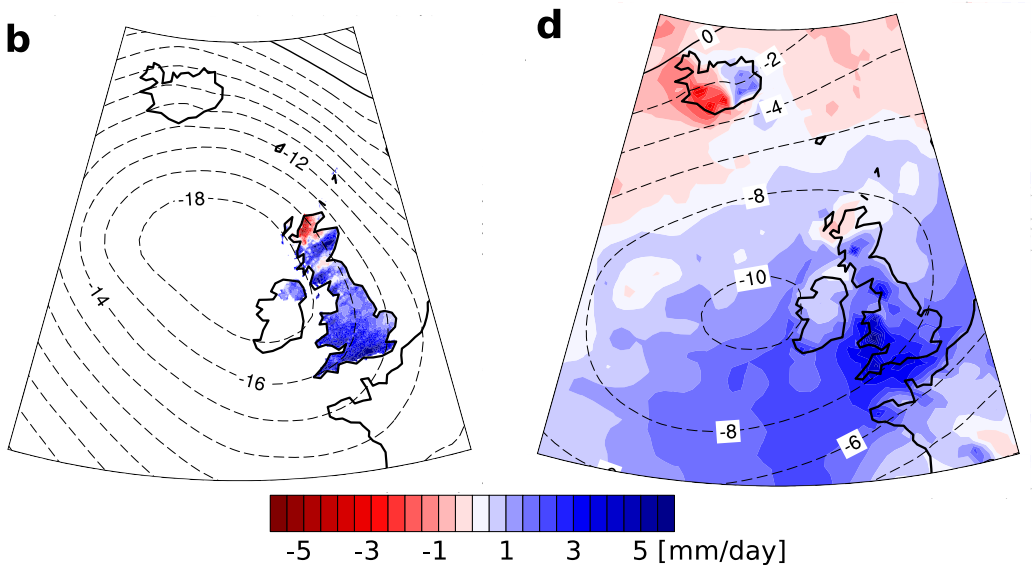
Chaos makes the attribution question interesting

- Extreme events may be more frequent than you would expect from a simple linear stochastic process (sandpile example).
- External drivers of climate change can affect *both*
  - The **magnitude** of an event, assuming it happens anyway.
  - The **probability** of a similar event happening at all.
- It can affect them in different ways.
- And both effects are interesting.

Change in probability of high Southern England rainfall

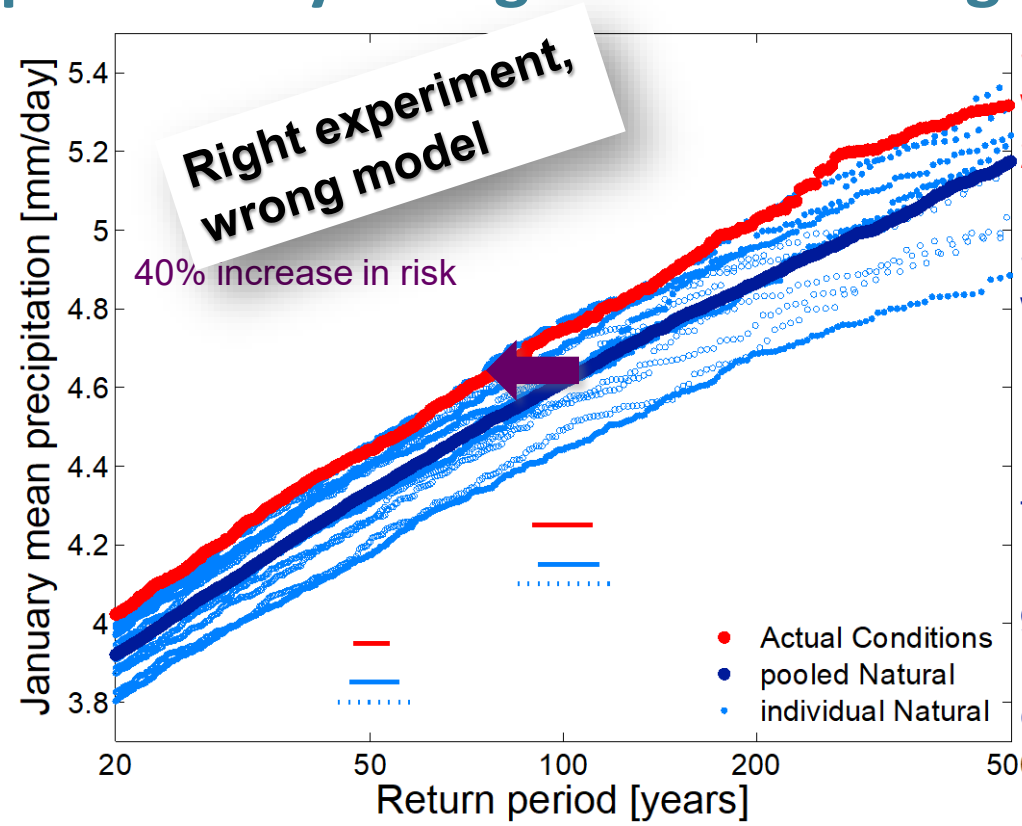
January 2014
observed precipitation
& pressure anomalies

Precipitation and pressure
anomalies in the wettest 1% of
the “actual conditions” ensemble



Schaller et al, 2016

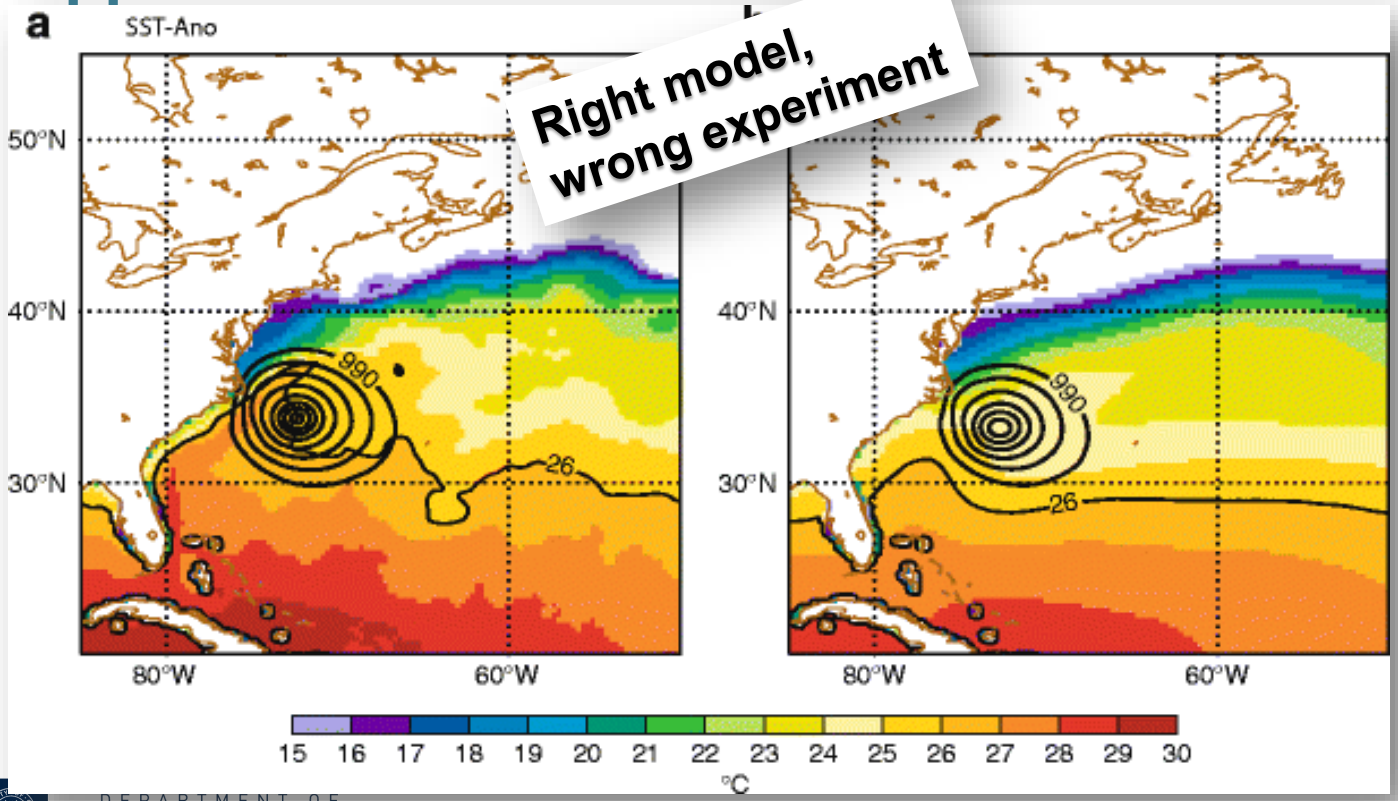
Change in probability of high Southern England rainfall



Simulations of the world as it was in 2014/15

Simulations of the world as it might have been without human influence: lower sea surface temperatures (incl. uncertainty); lower greenhouse gas levels (back to 19th century).

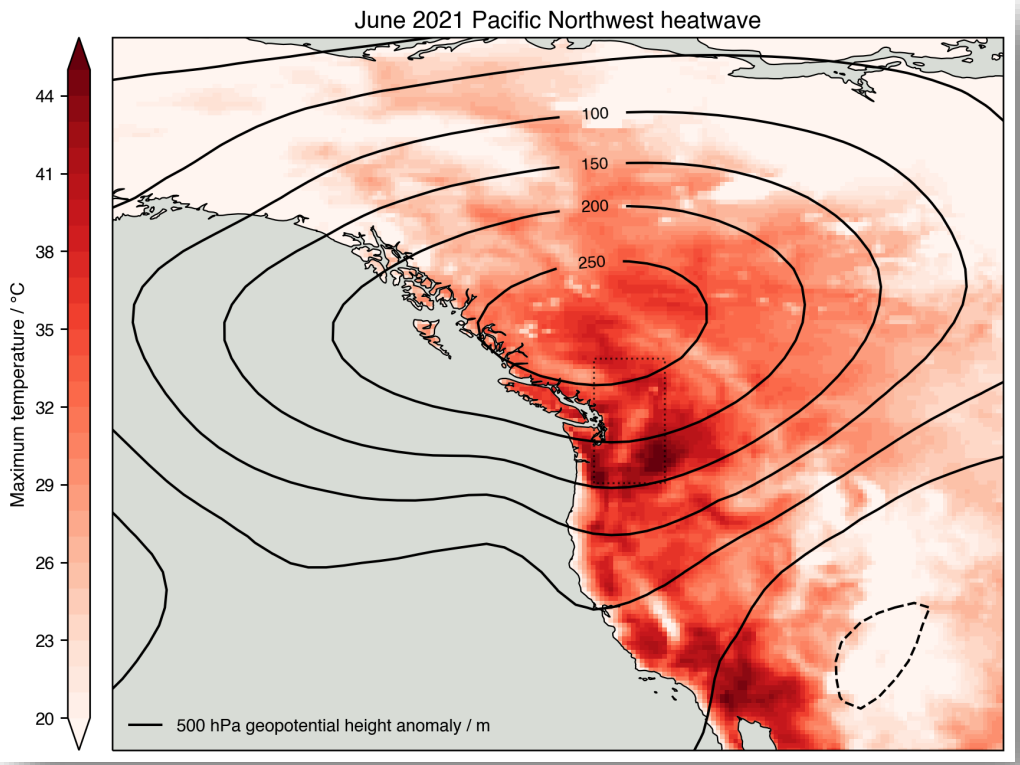
Introducing more realistic models: the “storyline” approach



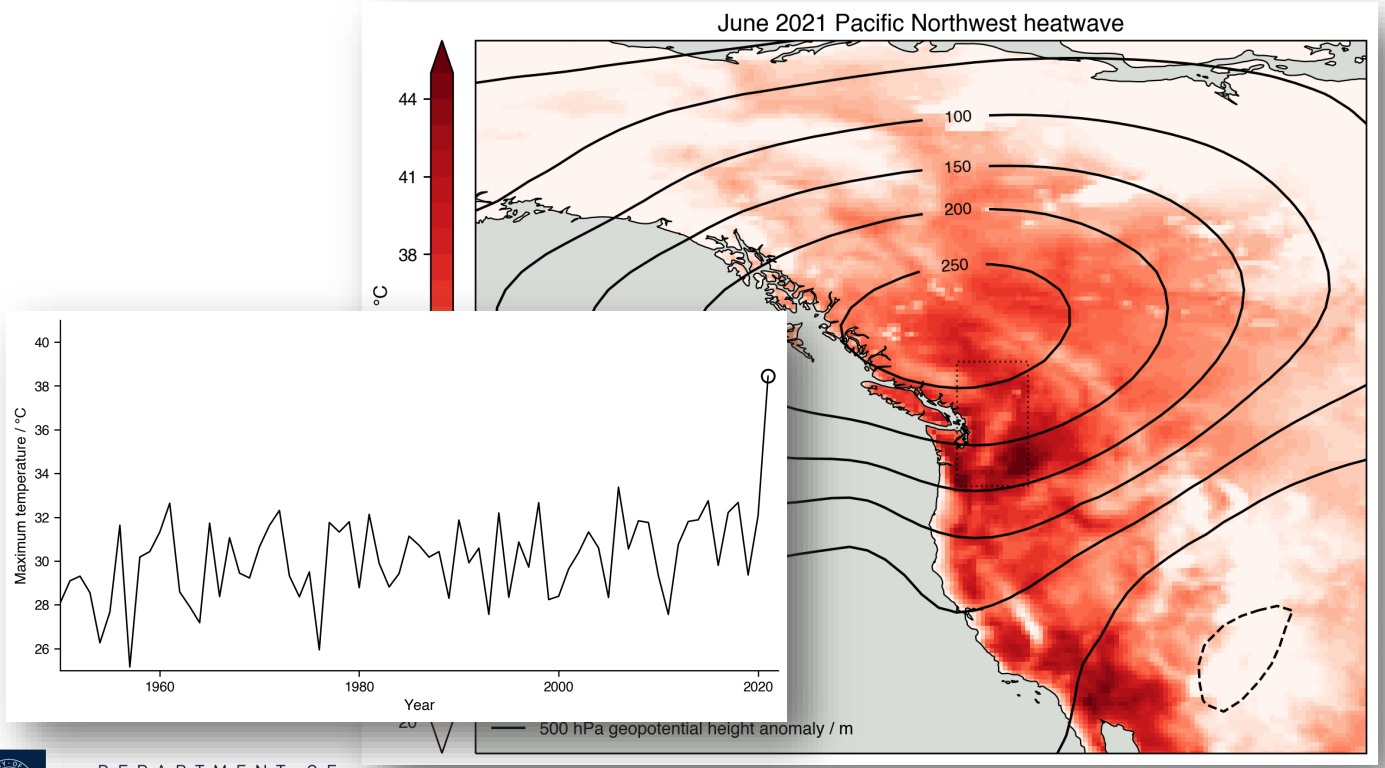
Hurricane Sandy with and without anomalous sea surface temperatures.

High-resolution model constrained to reproduce observed storm trajectory.

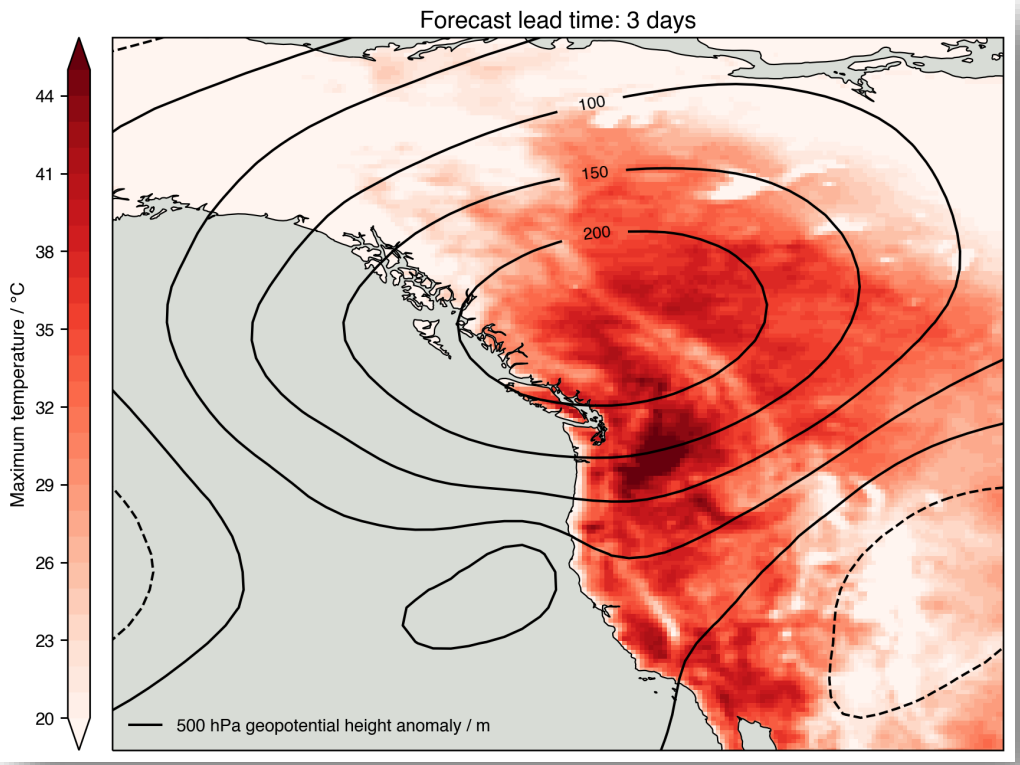
The June 2021 heatwave in the Pacific Northwest



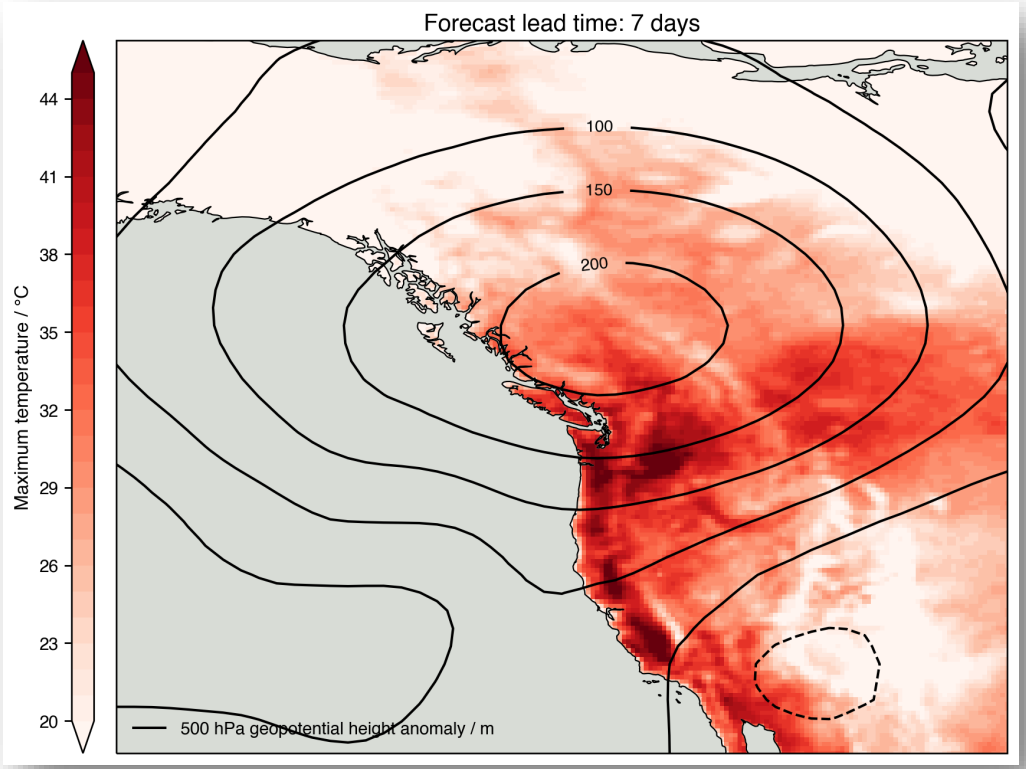
Apparently unprecedented



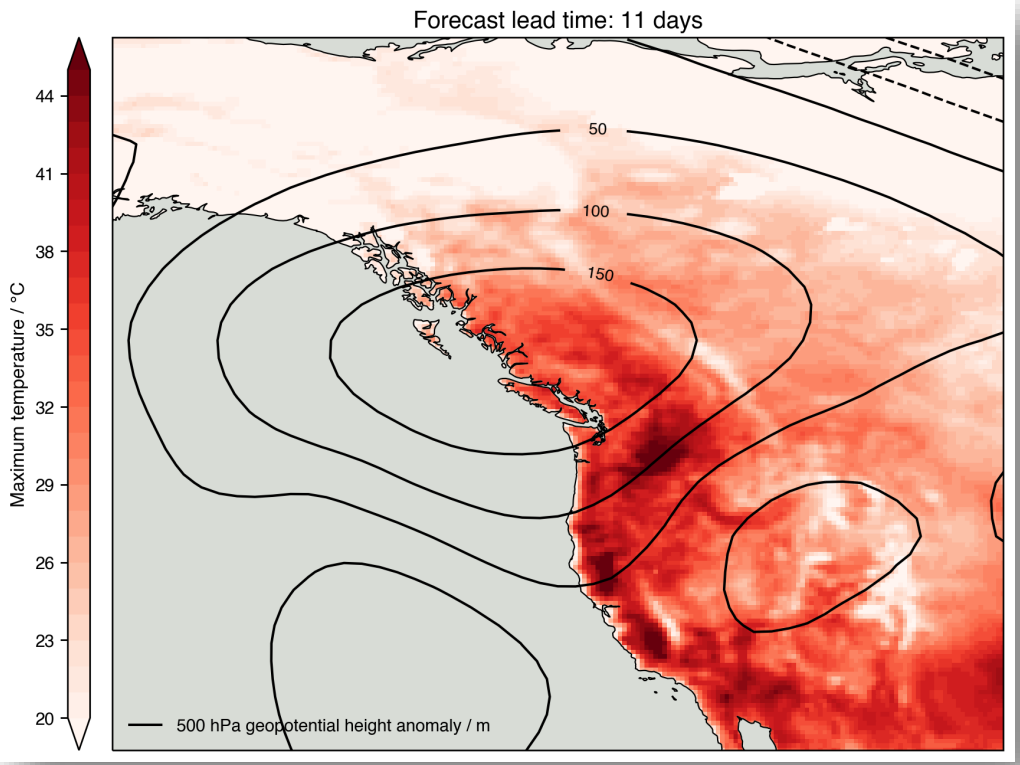
But remarkably well forecast: 3 days out



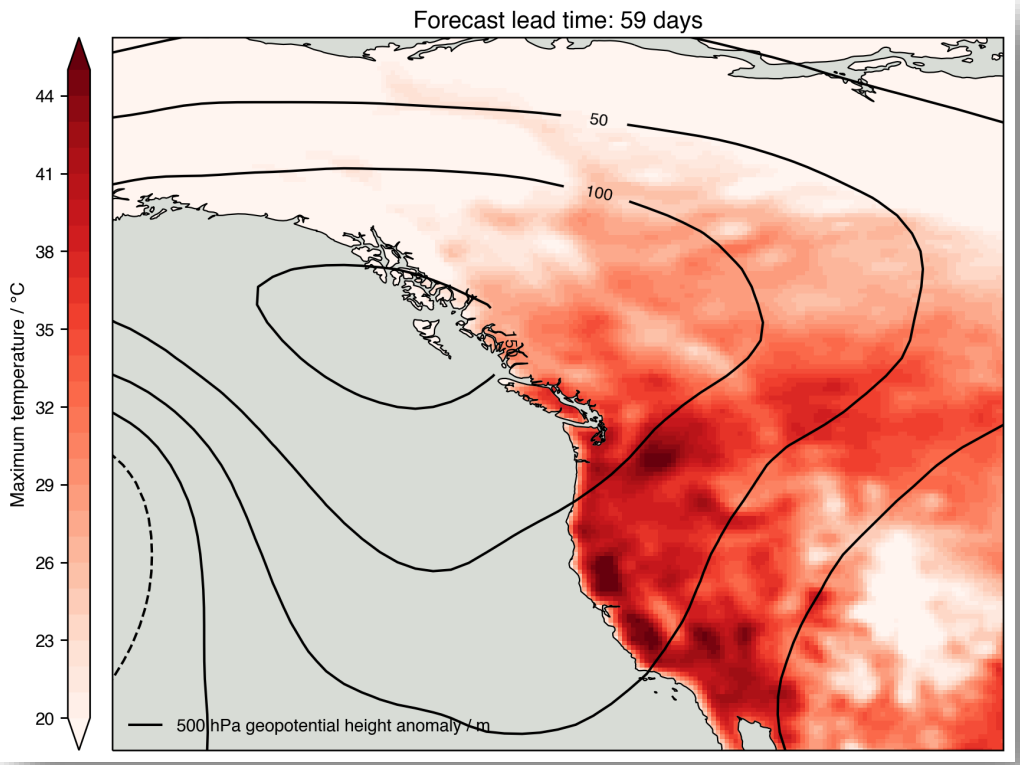
But remarkably well forecast: 7 days out



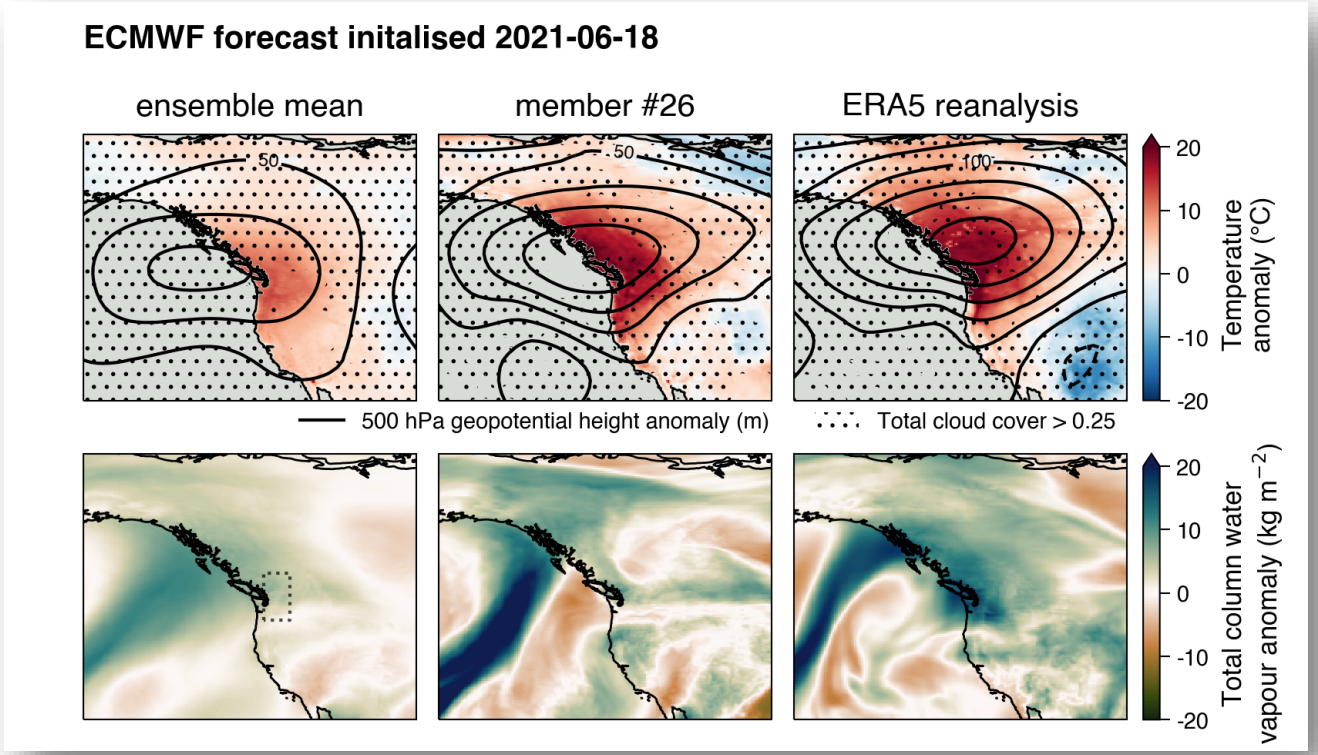
But remarkably well forecast: 11 days out



But remarkably well forecast: 2 months out



Capturing essential physics in the forecast model

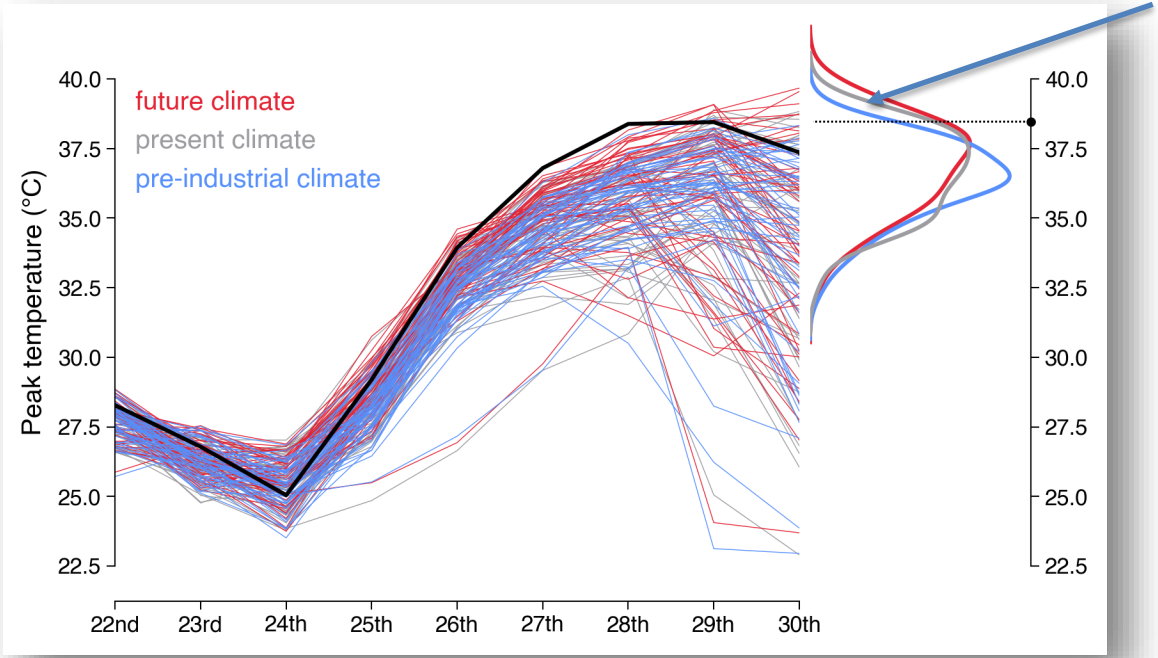


Forecast-based attribution with the operational medium-range and seasonal IFS (Leach et al, 2024)

- Reset CO_2 concentrations & modify initial conditions to subtract full 3-D pattern of ocean surface and sub-surface warming since 1900: "pre-industrial climate"
- Modify ocean salinities to conserve density
- Rerun the 50-member ensemble forecast at increasing lead times to explore impact on forecast probability of event
- Repeat increasing CO_2 and adding pattern of warming to check linearity of response: "future climate"

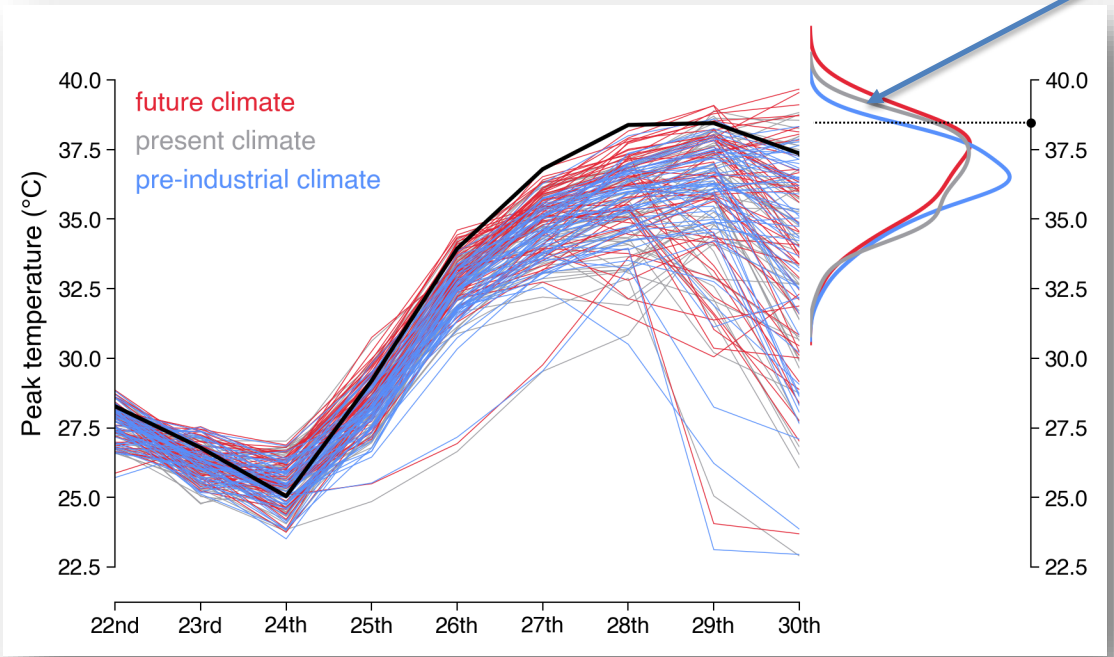
Impact of warming on probability of heatwave

8-fold increase in probability for a 1.2°C rise in global temperature



Impact of warming on probability of heatwave

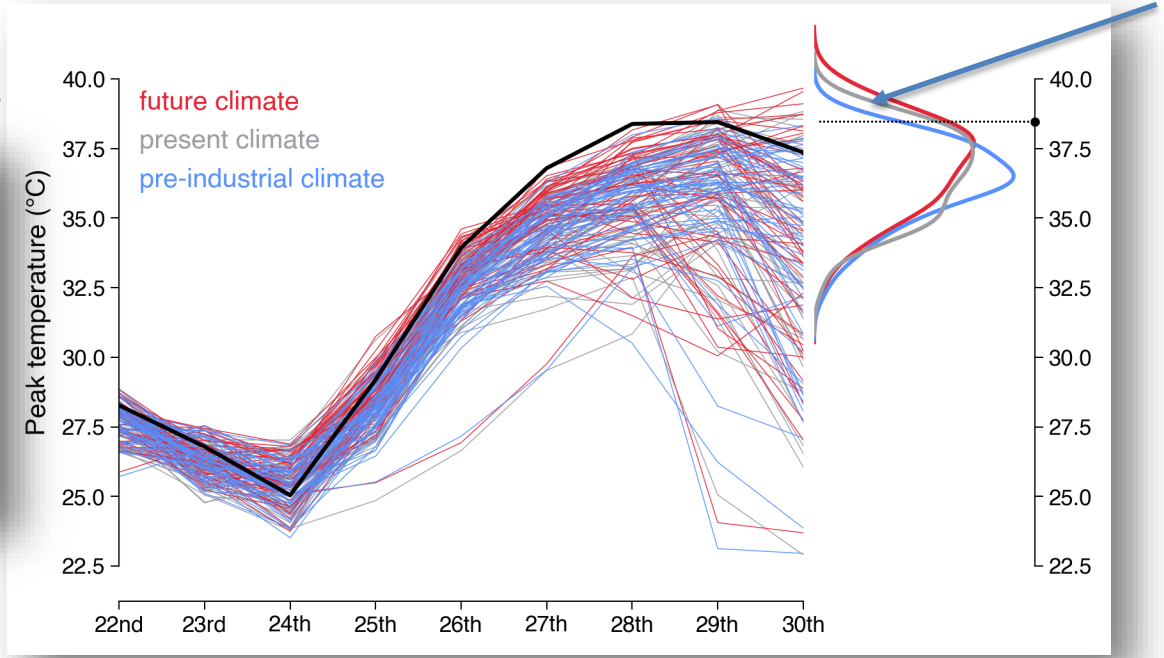
Probability doubling every 20 years



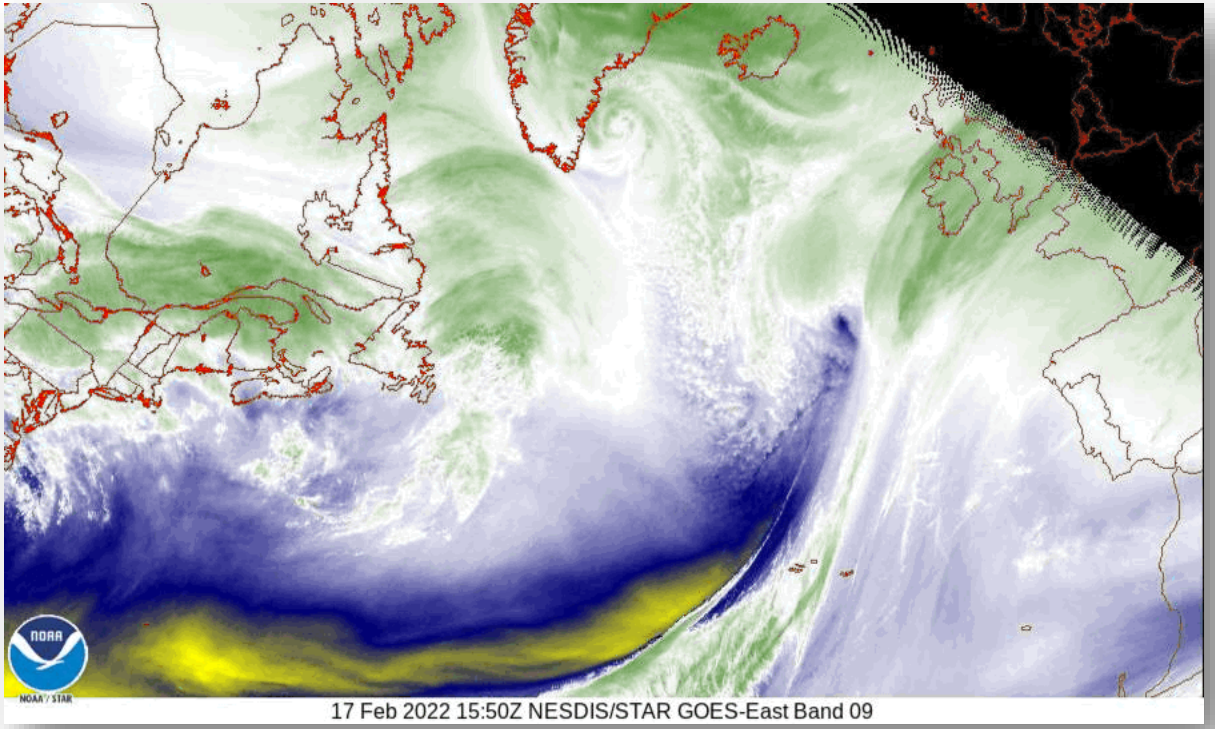
Impact of warming on probability of heatwave

Not "virtually impossible without climate change"

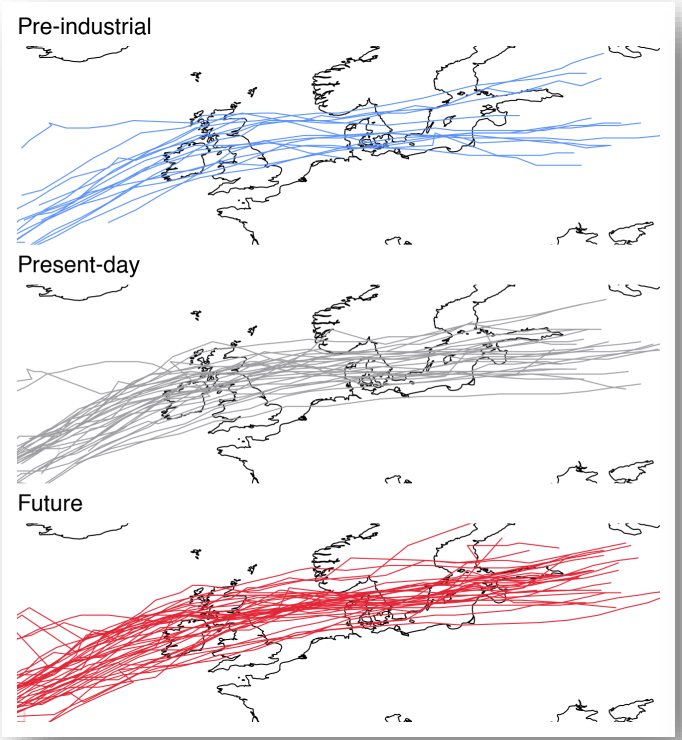
Leach et al, 2024

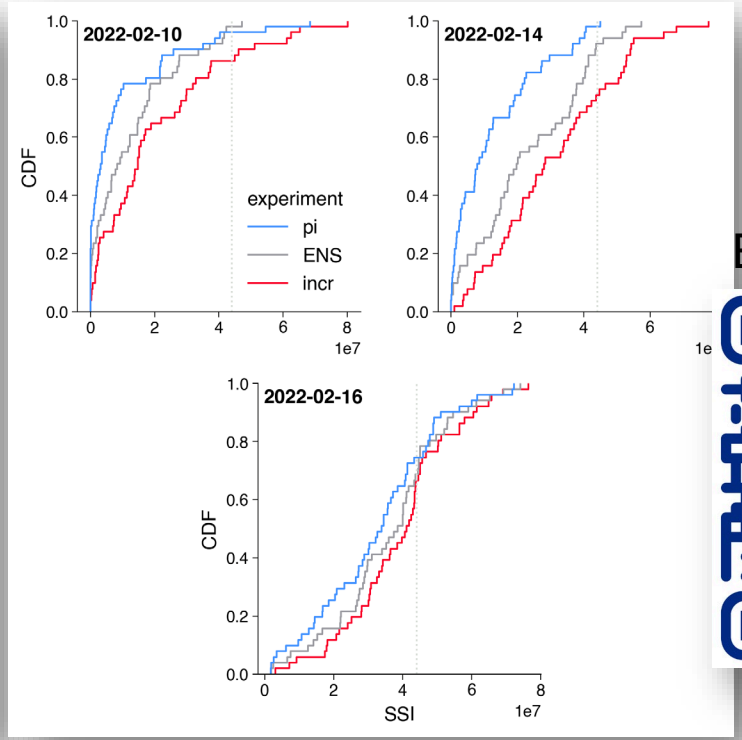


A more dynamical example: Storm Eunice, February 2022



Impact of anthropogenic climate change on ensemble forecasts of Storm Eunice at 2, 4 & 8-day leads





Ermis et al, 2024

SCAN ME

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ECMWF
CLIMATE X
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Challenges for forecast-based attribution of trends in event probabilities

- Target: rates of change of probability of similar extreme events in a free-running and reliable model.
  - Reliable extreme probabilities require accurate return-time slopes, which require a high-resolution (dynamical?) model.
  - Compromise on model for an adequate ensemble size.
  - Compromise on ensemble size for a reliable model.
  - Waste resources on “mindless” high-resolution ensembles.
- Use perturbed ensemble forecasts at progressively longer lead times to look for convergence of results.

Could the need for reliable event attribution be another driver of investment in more realistic models?